# CMPSC 274: Transaction Processing Lecture #6: Concurrency Control Protocols

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## Chapter 4: Concurrency Control Algorithms

- 4.2 General Scheduler Design
- 4.3 Locking Schedulers
- **4.4 Non-Locking Schedulers**
  - **4.4.1 Timestamp Ordering**
  - 4.4.2 Serialization-Graph Testing
  - 4.4.3 Optimistic Protocols
- 4.5 Hybrid Protocols
- 4.6 Lessons Learned

## (Basic) Timestamp Ordering

**Timestamp ordering rule (TO rule):**
Each transaction $t_i$ is assigned a **unique timestamp ts($t_i$)**
(e.g., the time of $t_i$'s beginning).
If $p_i(x)$ and $q_j(x)$ are in conflict, then the following must hold:
**$p_i(x) <_s q_j(x)$ iff $ts(t_i) < ts(t_j)$** for every schedule s.

**Theorem 4.15:**
Gen (TO) $\subseteq$ CSR.

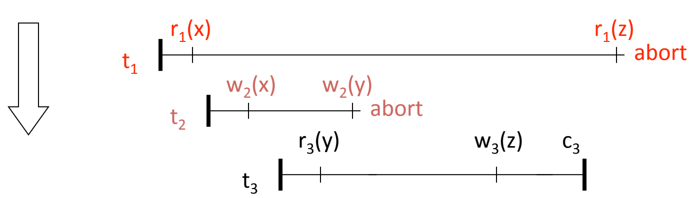
**Basic timestamp ordering protocol (BTO):**

- For each data item x maintain max-r (x) = max{ts($t_j$) | $r_j(x)$ has been scheduled} and max-w (x) = max{ts($t_j$) | $w_j(x)$ has been scheduled}.
- Operation $p_i(x)$ is compared to max-q (x) for each conflicting q:
  - if ts($t_i$) < max-q (x) for some q then abort $t_i$
  - else schedule $p_i(x)$ for execution and set max-p (x) to ts($t_i$)



## BTO Example

s = $r_1(x)$ $w_2(x)$ $r_3(y)$ $w_2(y)$ $c_2$ $w_3(z)$ $c_3$ $r_1(z)$ $c_1$




$r_1(x)$ $w_2(x)$ $r_3(y)$ $a_2$ $w_3(z)$ $c_3$ $a_1$

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## Serialization Graph Testing (SGT)

**SGT protocol:**

- For $p_i(x)$ create a new node in the graph if it is the first operation of $t_i$
- Insert edges $(t_j, t_i)$ for each $q_j(x) <_s p_i(x)$ that is in conflict with $p_i(x)$ $(i \neq j)$.
- If the graph has become cyclic then abort $t_i$ (and remove it from the graph) else schedule $p_i(x)$ for execution.

**Theorem 4.16:**
Gen (SGT) = CSR.

**Node deletion rule:**
A node $t_i$ in the graph (and its incident edges) can be removed when $t_i$ is terminated and is a source node (i.e., has no incoming edges).

**Example:**
$r_1(x)\ w_2(x)\ w_2(y)\ c_2\ r_1(y)\ c_1$
removing node $t_2$ at the time of $c_2$ would make it impossible to detect the cycle.

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## Optimistic Protocols

**Motivation:** conflicts are infrequent

**Approach:**
divide each transaction t into three phases:
- **read phase:**
  - execute transaction with writes into **private workspace**
- **validation phase (certifier):**
  - upon t's commit request
  - test if schedule remains CSR if t is committed now
  - based on t's read set RS(t) and write set WS(t)
- **write phase:**
  - upon successful validation
    - transfer the workspace contents into the database (**deferred writes**)
  - otherwise abort t (i.e., discard workspace)

## Backward-oriented Optimistic CC (BOCC)

Execute a transaction's validation and write phase together as a **critical section**: while $t_i$ being in the **val-write phase**, no other $t_k$ can enter its val-write phase

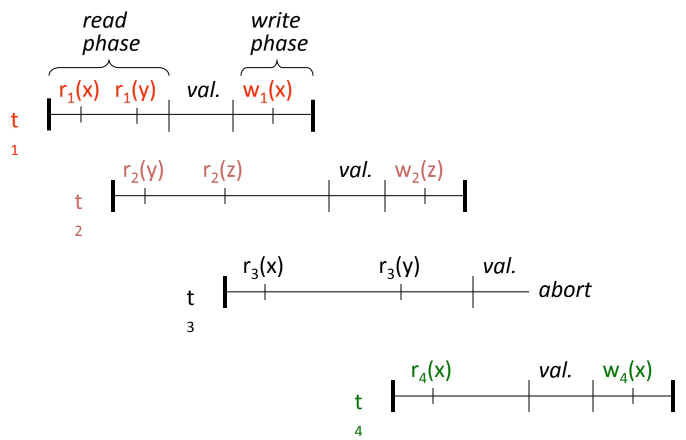
**BOCC validation** of $t_j$:
compare $t_j$ to all previously committed $t_i$
accept $t_j$ if one of the following holds
- $t_i$ has ended before $t_j$ has started, or
- $RS(t_j) \cap WS(t_i) = \emptyset$ and $t_i$ has validated before $t_j$

**Theorem 4.46:**
Gen (BOCC) $\subset$ CSR.

**Proof:**
Assume that G(s) is acyclic. Adding a newly validated transaction can insert only edges into the new node, but no outgoing edges (i.e., the new node is last in the serialization order).



## BOCC Example



## Forward-oriented Optimistic CC (FOCC)

Execute a transaction's val-write phase as a **strong critical section**:
while $t_i$ being in the **val-write phase**, no other $t_k$ can perform any steps.

**FOCC validation** of $t_j$:
compare $t_j$ to all concurrently active $t_i$ (which must be in their read phase)
accept $t_j$ if $WS(t_j) \cap RS^*(t_i) = \emptyset$ where $RS^*(t_i)$ is the current read set of $t_i$

Remarks:
- FOCC is much more flexible than BOCC:
  upon unsuccessful validation of $t_j$ it has three options:
  - abort $t_j$
  - abort one of the active $t_i$ for which $RS^*(t_i)$ and $WS(t_j)$ intersect
  - wait and retry the validation of $t_j$ later
    (after the commit of the intersecting $t_i$)
- Read-only transactions do not need to validate at all.

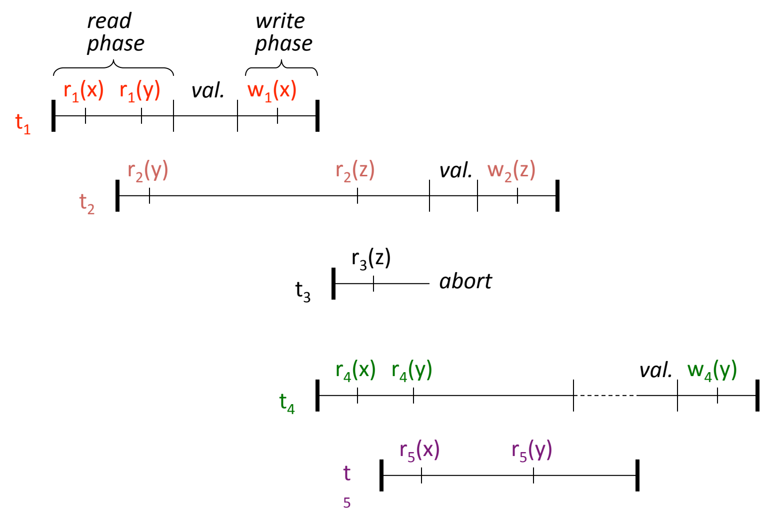


## Correctness of FOCC

**Theorem 4.18:**
Gen (FOCC) $\subset$ CSR.

**Proof:**
Assume that G(s) has been acyclic and that validating $t_j$ would create a cycle.
So $t_j$ would have to have an outgoing edge to an already committed $t_k$.
However, for all previously committed $t_k$ the following holds:
- If $t_k$ was committed before $t_j$ started, then no edge $(t_j, t_k)$ is possible.
- If $t_j$ was in its read phase when $t_k$ validated, then $WS(t_k)$ must be disjoint with $RS^*(t_j)$ and all later reads of $t_j$ and all writes of $t_j$ must follow $t_k$ (because of the strong critical section); so neither a wr nor a ww/rw edge $(t_j, t_k)$ is possible.

## FOCC Example



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## Hybrid Protocols

**Idea:** Combine different protocols,
each handling different types of conflicts (rw/wr vs. ww) or data partitions

**Caveat:** The combination must guarantee that the **union** of the underlying "local" conflict graphs is acyclic.

**Example 4.15:**
use SS2PL for rw/wr synchronization and TO or TWR for ww
with **TWR (Thomas' write rule)** as follows:
for $w_j(x)$: if $ts(t_j) >$ max-w (x) then execute $w_j(x)$ else do nothing

$s_1 = w_1(x)\ r_2(y)\ w_2(x)\ w_2(y)\ c_2\ w_1(y)\ c_1$
$s_2 = w_1(x)\ r_2(y)\ w_2(x)\ w_2(y)\ c_2\ r_1(y)\ w_1(y)\ c_1$

} both accepted by SS2PL/TWR with $ts(t_1) < ts(t_2)$, but $s_2$ is not CSR

**Problem with $s_2$:** needs synch among the two "local" serialization orders

**Solution:** assign timestamps such that the serialization orders of SS2PL and TWR are in line $\rightarrow ts(i) < ts(j) \Leftrightarrow c_i < c_j$



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## Lessons Learned

- S2PL is the most versatile and robust protocol
  and widely used in practice
- Knowledge about specifically restricted access patterns
  facilitates non-two-phase locking protocols (e.g., TL, AL)
- O2PL and SGT are more powerful but have more overhead
- FOCC can be attractive for specific workloads
- Hybrid protocols are conceivable but non-trivial